Navigating Mars Observer: Launch Through Encounter and Response to the Spacecraft's Pre-Encounter Anomaly.

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ABSTRACT

This paper provides an in-depth review of the Mars Observer Navigation Team's activities throughout interplanetary cruise to Mars and our response to the spacecraft's anomaly which occurred approximately 68 hours before encounter.

Nominal launch and encounter times along with the three completed trajectory correction maneuvers (TCM) and Mars orbit insertion (MOI) planning are summarized in Table 1. The targeting results of the Transfer Orbit Stage (TOS) injection and three TCM's are summarized in Fig. 1. This figure represents a target plane or coordinate system centered on Mars. As indicated, the result of each TCM is to progressively direct the spacecraft to the final aimpoint. The nominal aimpoint was over the northern polar region at an areocentric distance of 3950 krn and encounter time of 24 August 1993, 20:41:00 UTC. The final orbit determination results and the one-sigma uncertainties for planning the MOI maneuver are summarized as follows:

B*T (km)	= 7.1 ± 10.
B•R (km)	-8397.1 ±18.
Encounter Time (LJ1 C, SCET)	= 24 August 1993, 20:40:06 ± 5.3 Sec

These orbit deterrnination results coupled with the MOI maneuver and execution uncertainties yielded capture orbit elements and expected errors given in Table 2.

The orbit determination analysis utilized three tracking data types: two-way coherent doppler (or range rate), round-trip travel time (or range) and Very Long Baseline Interferometry (VLBI) determined angles. Data acquisition (doppler and range) was continuous during launch and on approach to Mars and reduced during the remainder of cruise. On average, VLBI data was acquired once per week. One of our first tasks, was to evaluate the inherent quality of the doppler and range data. I-he initial assessment was made using data acquired during the first half-hour of flight operations and is summarized in Table 3. The inherent data quality easily exceeded our requirements.

A spacecraft anomaly occurred at MOI minus 68 hours resulting in the loss of telecommunications with the Deep Space Network (DSN) tracking stations. Nevertheless, it was still possible that the critical capture orbit maneuver might have been executed as originally scheduled because the complete sequence of commands had been transmitted to the spacecraft earlier. However since the nature of the anomaly was unknown, contingency plans were developed to address the possibility that the capture maneuver may have not executed arid the spacecraft could be on a flyby trajectory.

In order to be prepared for the flyby contingency, a maneuver design was prepared such that if executed 24 to 36 hours after encounter, the spacecraft could be inserted into a Mars capture orbit. * However the orbital period would be about 40 days and all the hi-propellant velocity-change capability would be exhausted. The remaining hi-propellant velocity-change capability was 2246 m/sec. If spacecraft communications were not established within this time period then a second contingency plan was developed. This plan involved executing a maneuver one month after encounter thus allowing a second encounter with Mars ten months after the original encounter. Preliminary analysis indicated that a post-MOI mapping orbit with an orbital period of 12 to 18 hours would be possible. Since communications were not established, neither **of these** contingencies were implemented.

The last section discusses predicted spacecraft ephemerides for a capture and flyby scenario and some of the plans that were developed to search for Mars Observer. Figure 2 is an orbital overview for both the capture orbit and flyby possibilities.

•The original idea for this contingency was developed by R. Roncoli and members of the mission design team.

Table 1
Mars Observer Propulsive Maneuver Operations and Plan

Event	Date	Velocity Change ΔV (m/s)	Burn Duration ΔT (see]	Engines	Purpose
Launch	9-25-92			–	..
TCM-1	10-10-92	50.0	5.0 (ullage) 133.8	490N (1,3)	Correct Titan III/TOS Injection Errors
TCM-2	2-08-93	9.65	5.0 (ullage) 29.4	490N (2,4)	
TCM-3	3-18-93	0.46	17.4	22N (4,5,6,7)	Correct TCM-2 Errors and Implement "Power-in" Strategy
MOI	8-24-93	761.7	5.0 (ullage) 1720.	490 N(1,3)	Accomplish Capture into 75 hour Orbital Period and Initiate Phobos Encounter Strategy
ECM-1	9-03-93	65.9			"Power-in" maneuver. Primarily out-of-plane in order to change the longitude of ascending node. Also prepare for Phobos encounters.
ECM-2	9-15-93	129.8			Change orbital period to near 3:1 Phobos resonance

Table 3
Doppler and Range Inherent Noise Evaluated from the First Half-Hour of Flight Operations Data

Tracking Data	Quantity	count Time (see)	Standard Deviation (mHz)	(mm/sec)	Requirement (one sigma-mm/sec)
Two-way	1674	1	22.5	0.40	
Coherent	166	10	3.67	0.065	
Doppler	27	60	1.12	0.021	0.2
	Quantity		Standard Deviation (Range Units)	(Meters)	Requirement (one sigma- meters)
Sequential Ranging Assembly (SRA) Range	49		0.50	0.07	5

Table 2
Nominal Capture Orbit Elements and Resultant Uncertainties

Orbital Element	Nominal Value	One-Sigma Uncertainty
Semi-major Axis (km)	42,946.7	--
Period (days)	3.125	1.6 hours
Eccentricity	0.9094	--
Longitude of Ascending Node (deg)	-106.72	0,046
Inclination (deg)	89.96	0.070
Argument of periapsis (deg)	116.50	0.14
Epoch (Apoapsis; UTC/SCET)	8-26-93 10:12:04	
Coordinate System	Mars centered, inertial, Mars mean equator and equinox of date	

INTERPLANETARY TARGETING

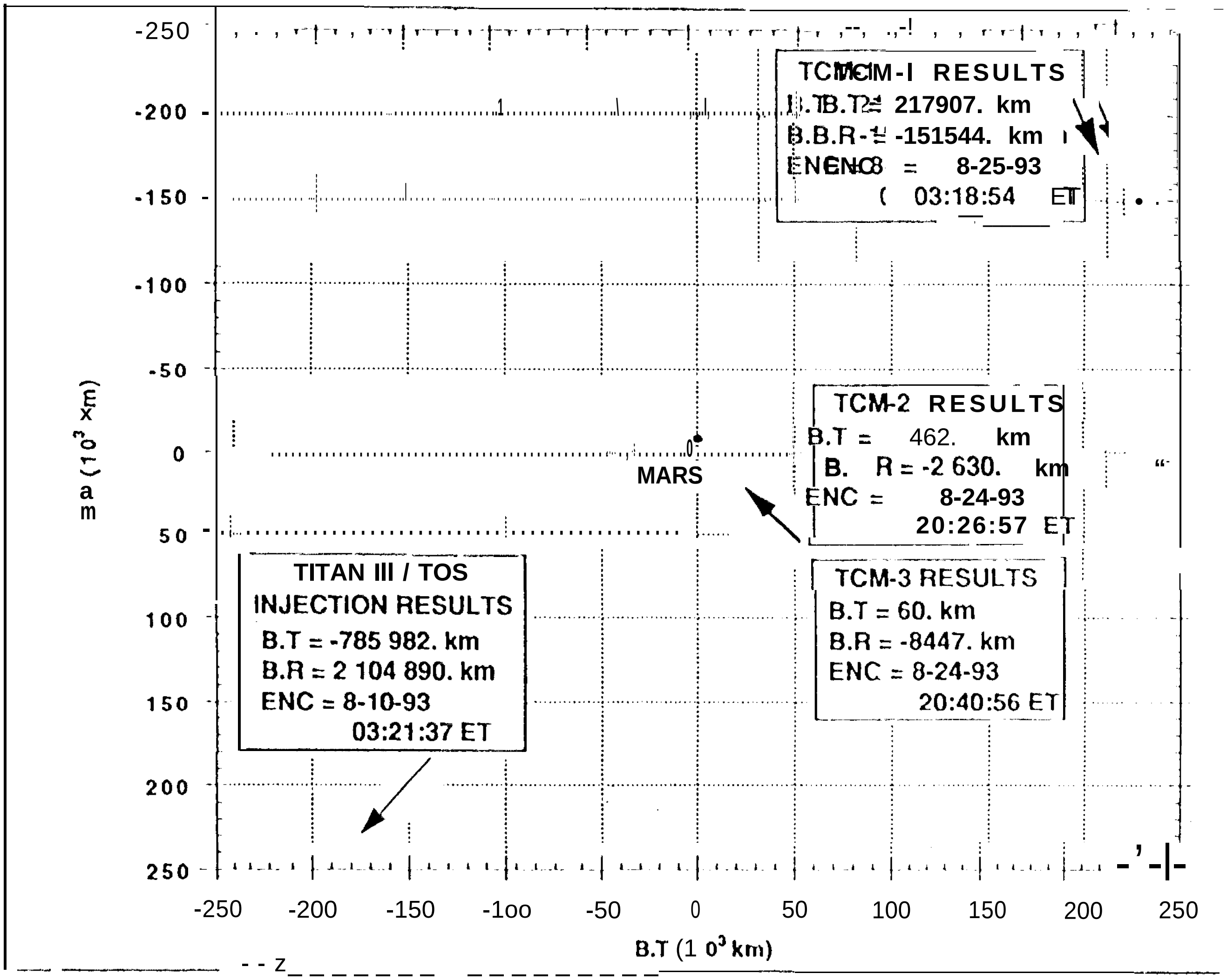
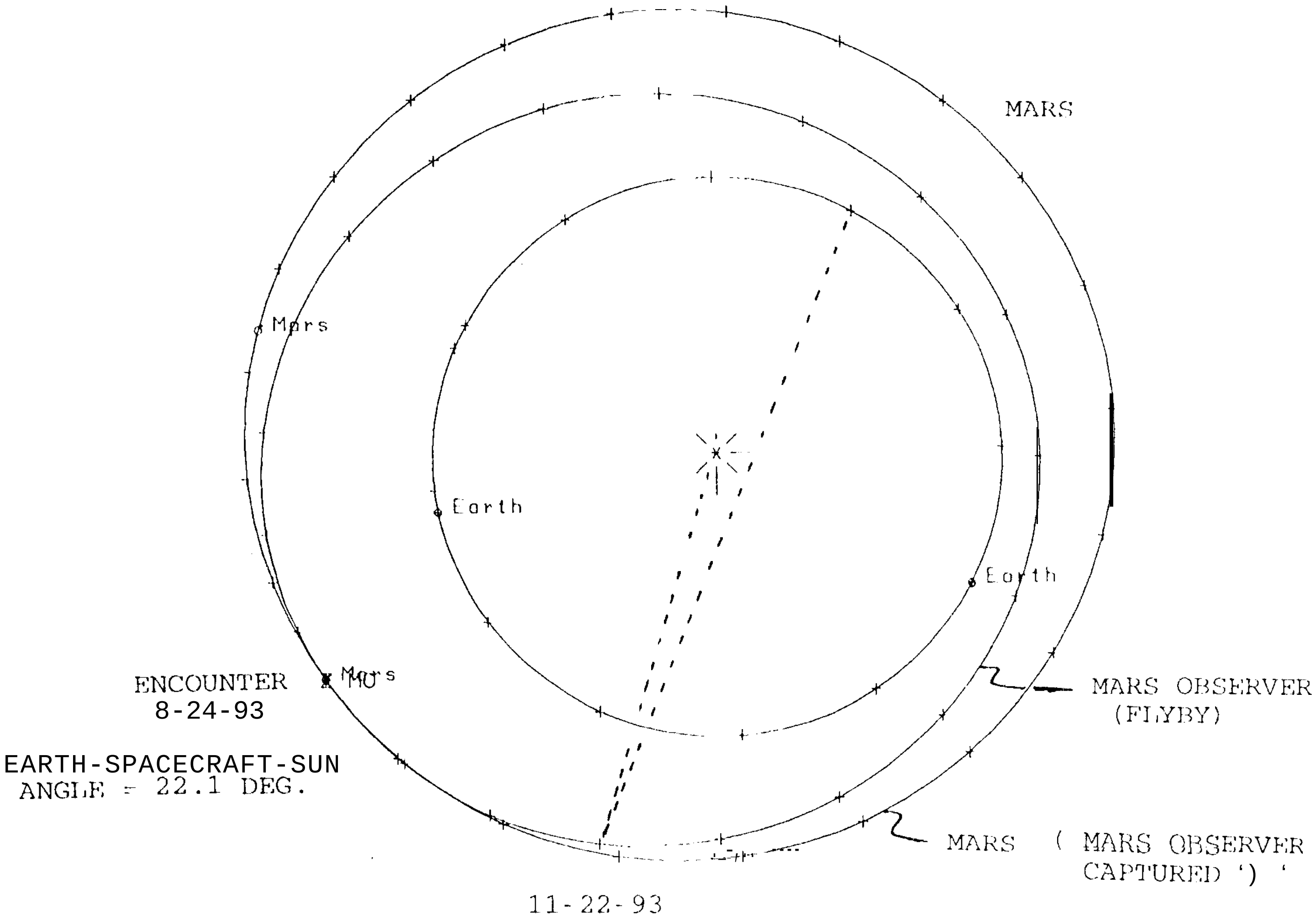


Figure 1

MARS OBSERVER CAPTURE AND FLYBY ORBITS



ECLIPTIC PLANE

TICKS: 30 DAY INTERVALS

Figure 2